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ORGANIC VERTICAL CAVITY LASER
ARRAY DEVICE WITH VARYING PIXEL SIZES
CROSS REFERENCE TO RELATED APPLICATIONS

Reference is made to commonly assigned U.S. Patent Application

5   Serial No. 09/832,759 filed April 11, 2000 entitled "Incoherent Light-Emitting

Device Apparatus for Driving Vertical Laser Cavity" by Keith B. Kahen et al.;

commonly assigned U.S. Patent Application Serial No. _____ filed June 24,

2003 entitled "Incoherent Light-Emitting Device Apparatus for Driving Vertical

Laser Cavity" by Keith B. Kahen et al.; commonly assigned U.S. Patent

10   Application Serial No. 10/066,936 filed February 4, 2002 entitled "Organic

Vertical Cavity Lasing Devices Containing Periodic Gain Regions" by Keith B.

Kahen et al.; commonly assigned U.S. Patent Application Serial No. 10/066,829

filed February 4, 2002 entitled "Organic Vertical Cavity Phase-Locked Laser

Array Device" by Keith B. Kahen et al.; commonly assigned U.S. Patent

15   Application Serial No. _____ filed _____ entitled "Providing an

Improved Organic Vertical Cavity Laser Array Device" by Keith B. Kahen et al.;

and commonly assigned U.S. Patent Application Serial No. _____ filed

June 30, 2003 entitled "Providing an Organic Vertical Cavity Laser Array Device

With Etched Region in Dielectric Stack" by Keith B. Kahen, the disclosures of

20   which are incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates to a way of making an organic

vertical cavity laser light producing device.

BACKGROUND OF THE INVENTION

25   Vertical cavity surface emitting lasers (VCSELs) based on

inorganic semiconductors (e.g. AlGaAs) have been developed since the mid-80's

(K. Kinoshita et al., IEEE J. Quant. Electron. QE-23, 882 [1987]). They have

reached the point where AlGaAs-based VCSELs emitting at 850 nm are

manufactured by a number of companies and have lifetimes beyond 100 years

30   (K.D. Choquette et al., Proc. IEEE 85, 1730 [1997]). With the success of these

near-infrared lasers in recent years, attention has turned to other inorganic material

systems to produce VCSELs emitting in the visible wavelength range

(C. Wilmsen et al., *Vertical-Cavity Surface-Emitting Lasers*, Cambridge University Press, Cambridge, 2001). There are many fruitful applications for visible lasers, such as, display, optical storage reading/writing, laser printing, and short-haul telecommunications employing plastic optical fibers (T. Ishigure et al.,

5   Electron. Lett. 31, 467 [1995]). In spite of the worldwide efforts of many industrial and academic laboratories, much work remains to be done to create viable laser diodes (either edge emitters or VCSELs), which span the visible spectrum.

In the effort to produce visible wavelength VCSELs, it would be

10   advantageous to abandon inorganic-based systems and focus on organic-based laser systems, since organic-based gain materials can enjoy the properties of low unpumped scattering/absorption losses and high quantum efficiencies. In comparison to inorganic laser systems, organic lasers are relatively inexpensive to manufacture, can be made to emit over the entire visible range, can be scaled to

15   arbitrary size, and most importantly, are able to emit multiple wavelengths (such as red, green, and blue) from a single chip.

The usual route for making a manufacturable laser diode system is to use electrical injection rather than optical pumping to create the necessary population inversion in the active region of the device. This is the case for

20   inorganic systems since their optically pumped thresholds (P.L. Gourley et al., Appl. Phys. Lett. 54, 1209 [1989]) for broad-area devices are on the order of 10^4 W/cm^2. Such high power densities can only be achieved by using other lasers as the pump sources, precluding that route for inorganic laser cavities. Unpumped organic laser systems have greatly reduced combined scattering and absorption

25   losses ($\sim$0.5 cm^{-1}) at the lasing wavelength, especially when one employs a host-dopant combination as the active media. As a result, optically pumped power density thresholds below 1 W/cm^2 should be attainable, especially when a VCSEL-based microcavity design is used in order to minimize the active volume (which results in lower thresholds). The importance of power density thresholds

30   below 1 W/cm^2 is that it becomes possible to optically pump the laser cavities with inexpensive, off-the-shelf, incoherent LED's.

In order to produce multimode milliwatt laser output power from an organic VCSEL device, typically it is necessary to have the diameter of the emitting area be on the order of 10 µm. As a result, 1 mW of output power would require that the device be optically pumped by a source producing ~4000 W/cm^2

5   (assuming a 25% power conversion efficiency). This power density level (and pixel size) is far beyond the capabilities of LED's and, additionally, would most likely cause some degradation problems with the organic materials if they were driven cw. A path around that problem is to increase the organic laser's emitting area diameter to around 350 µm, which would reduce the pump power density

10   level to 4 W/cm^2 (to produce 1 mW of output power). This power density level and pixel size is achievable by off-the-shelf 400 nm inorganic LED's. Unfortunately, broad-area laser devices having 350 µm diameter emitting areas would lead either to filamented multimode laser output (which is hard to control) or to resonant cavity LED action (which is not lasing). Either way, the power

15   conversion efficiency would be lower.

SUMMARY OF THE INVENTION

It is an object of the present invention to produce a large area organic VCSEL device, which has good power conversion efficiency and has controllable multimode laser output.

20   It is a further object of this invention to provide a way of making an organic surface emitting laser arrangement that is particularly suitable to permit multimode laser emission from a two-dimensional array of randomly sized and spaced micron-sized organic laser pixels.

These objects are achieved by an organic vertical cavity laser array

25   device for producing multimode laser output, comprising:

a)   a substrate;

b)   a bottom dielectric stack reflective to light over a predetermined range of wavelengths and being disposed over the substrate;

c)   an active region for producing laser light;

30   d)   a top dielectric stack spaced from the bottom dielectric stack and reflective to light over a predetermined range of wavelengths;

e)   the active region includes one or more periodic gain region(s) and spacer layers disposed on either side of the periodic gain region(s) and arranged so that the periodic gain region(s) is aligned with the antinodes of the device's standing wave electromagnetic field;

5   f)   means for providing an array of spaced laser pixels which have higher reflectance than the interpixel regions; and

g)   the spaced laser pixels having different sizes and the spacings between pixels having the same or different lengths to cause the vertical cavity laser array device to produce multimode laser output.

10   **ADVANTAGES**

It is an advantage of the present invention to provide a way of making a two-dimensional organic laser array device employing randomly sized and spaced micron-sized laser pixels which can be optically driven by large area sources and produce multimode laser output. The devices employ a microcavity

15   design incorporating high reflectance dielectric stacks for both the top and bottom reflectors; and have a gain media including organic material. The micron-sized laser pixels of the device are provided by modulating the reflectance of the bottom dielectric stack. As a result of randomly varying the position, size and spacing of the laser pixels, through the etch of the bottom dielectric stack, it is possible to

20   obtain laser emission whose spectral width and angular distribution is narrowed compared to periodic arrays of laser pixels.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a side view schematic of an optically pumped two-dimensional organic vertical cavity laser array made in accordance with the

25   present invention whereby the reflectance modulation is obtained by etching the top surface of the bottom dielectric stack;

FIG. 2 shows a top view schematic of an optically pumped two-dimensional organic vertical cavity laser array made in accordance with the present invention;

30   FIG. 3 shows a further embodiment of an optically pumped two-dimensional organic vertical cavity laser array made in accordance with the present invention which incorporates a planarization layer;

FIG. 4 shows a side view schematic of an optically pumped two-dimensional organic vertical cavity laser array made in accordance with the present invention whereby the reflectance modulation is obtained by etching the top surface of the first portion of the bottom dielectric stack;

FIG. 5 shows a further embodiment of the optically pumped two-dimensional organic vertical cavity laser array of FIG. 4 made in accordance with the present invention which incorporates a planarization layer; and

FIG. 6 shows a graph of intensity vs. wavelength and depicts the laser emission spectra for an optically pumped two-dimensional organic vertical cavity laser array as a function of the tilt angle of the sample.

DETAILED DESCRIPTION OF THE INVENTION

To enable a large area laser structure which emits spectrally and angularly narrowed multimode laser light, it is necessary to construct a two-dimensional laser array device **100** as shown schematically in FIG. 1 and in accordance with the present invention. FIG. 2 shows a top-view schematic of the two-dimensional laser array device **100** where on the surface of the VCSEL needs to be defined lasing pixels **200** separated by interpixel regions **210**. If single mode lasing action were desired, then the emission from the various pixels needs to be phase-locked, i.e., intensity and phase information must be exchanged amongst the pixels (E. Kapon and M. Orenstein, U.S. Patent 5,086,430). In addition the pixels need to be the same size and positioned in a periodic array. For phase-locked two-dimensional VCSEL structures, the common means for defining the laser pixels is to modulate the reflectance of the top dielectric stack by either adding metal (E. Kapon and M. Orenstein, U.S. Patent 5,086,430) or by deep etching into the top dielectric stack (P.L. Gourley et al., Appl. Phys. Lett. 58, 890 [1991]). In both inorganic laser array cases, the laser pixels were on the order of 3-5 μm wide (so as to enable single-mode action) and the interpixel spacing was 1-2 μm. Applying these results to organic laser systems requires some care since it is very difficult to perform micron-scale patterning on the laser structure once the organic layers have been deposited. As a result, in the preferred embodiment the reflectance of the bottom dielectric stack needs to be modulated. It has been found that modulating the reflectance by adding metal is difficult to control since

the modulation is only effective over a very narrow (<1 nm) wavelength range. Consequently, in this embodiment the modulation is obtained by performing a two-dimensional etch of the bottom dielectric stack, such that the interpixel regions **210** correspond to the etched regions (lower overall reflectance at the

5   lasing wavelength) of the bottom dielectric stack, whereas the unetched regions (higher overall reflectance at the lasing wavelength) correspond to the laser pixels **200**. Forming a one-dimensional array of laser pixels **200** is possible, even though it is not preferred in most instances since it would lead to poorer conversion of the incoming optical pump-beam power.

10   Even though the formation of the laser pixels **200** via reflectance modulation can lead to phase-locked single-mode action in the best case, if phase-locking is only localized or if higher-order modes are prevalent, then multimode lasing action will occur. For optically-driven laser array structures where the gain region is uniformly pumped, the appearance of higher-order array modes is

15   difficult to avoid when the laser pixels are placed periodically on a two-dimensional array. More specifically, the desired lowest-order array mode occurs by vertical (normal to the device surface) resonance on the same laser pixel, whereas, the higher-order array modes occur by tilted resonance on adjoining laser pixels. As the order of the array mode increases, the resonance tips at an

20   increasing angle and for each pass links increasingly separated laser pixels. The impact on the device output of these higher-order array modes is that even though the spectral width of each array mode is very narrow, the array modes can span greater than 20 nm in aggregate. In addition, since the higher-order array modes exit the device surface at increasing angles, the angular extent of the aggregate of

25   modes is also enlarged. Given these comments with regard to the higher-order array modes, a means for minimizing them is to randomly size and space the laser pixels, while placing them randomly in a two-dimensional array. This type of arrangement of the laser pixels is shown in FIG. 2. In actual practice, the size and positioning of the pixels is chosen randomly, which results in the random spacing

30   of the laser pixels. As a result of this randomization process, the higher-order array modes are minimized since the laser light would encounter different pixel environments for each pass when its path is tilted with respect to the surface

normal. Another possible laser pixel **200** arrangement is to randomly size the pixels, while keeping their centers on a periodic two-dimensional array.

Referring back to FIG. 1, the substrate **110** can either be light transmissive or opaque, depending on the intended directions of optical pumping and laser emission. The substrate **110** can be transparent glass or plastic. Alternatively, opaque substrates including, but not limited to, semiconductor materials (e.g., silicon) or ceramic materials can be used in the case where optical pumping and laser emission occur from the same surface. On the substrate **110** is deposited a bottom dielectric stack **120** which is composed of alternating high and low refractive index dielectric materials. In general, the bottom dielectric stack **120** is designed to be reflective to laser light over a predetermined range of wavelengths. Typical high and low refractive index materials are TiO_2 and SiO_2, respectively. The bottom dielectric stack **120** is deposited by standard electron-beam (e-beam) deposition or sputtering, where a typical e-beam deposition temperature is 240°C. For cases where additional dielectric layers are added to the bottom stack for reflecting a pump-beam **180** back into an active region **130**, these layers are to be deposited first in the bottom dielectric stack **120**.

In order to modulate the reflectance of the bottom dielectric stack **120**, an etched region **150** is formed on its surface by using standard photolithographic and etching techniques, thus forming a two-dimensional random array of randomly-sized circular pillars on the surface of the bottom dielectric stack **120**. In the preferred embodiment the shape of the laser pixels is circular; however, other pixel shapes are possible, such as, rectangular. The diameter of the laser pixels can be in the range of 2.5 to 20 μm. However, in order to minimize the angular spread of the laser output, the emission from the individual pixels should be kept to single mode, which would limit the pixel diameter to a range of 2.5 to 3.5 μm. With regard to the interpixel spacing, a preferred range is 0.25 to 4 μm. However, given the limits of standard photolithographic processes and the desire to maximize the power conversion efficiency, the more preferred interpixel spacing range is 0.5 to 1.0 μm. Via experimentation it has been determined that either one or two periods of the

bottom dielectric stack **120** should be removed to create the etched region **150**. Etching deeper than this typically resulted in laser arrays with poorer performance. With regard to creating the random pixel arrangement shown in FIG. 2, a photolithography mask containing randomly sized and positioned circles

5   can be formed using random packing algorithms commonly practiced in the art.

The active region **130** is deposited over the etched surface of the bottom dielectric stack **120**. FIG. 1 shows that the active region **130** is not a bulk layer but a multilayer composite. Following the suggestions of Brueck et al. (U.S. Patent 4,881,236) for inorganic lasers, the active region **130** contains one or more

10   periodic gain regions **160**, which are separated by spacer layers **170**. The thickness of the periodic gain regions **160** is typically less than 50 nm, with a preferred thickness of 5 to 30 nm. The thicknesses of the spacer layers **170** are chosen such that the periodic gain region(s) **160** is aligned with the antinodes of the laser cavity's standing electromagnetic-field (e-field). Employing periodic

15   gain region(s) in the active region results in larger power conversion efficiencies and a large reduction in the unwanted spontaneous emission. In summary, the active region **130** includes one or more periodic gain regions **160** and spacer layers **170** disposed on either side of the periodic gain region(s) and arranged so that the periodic gain region(s) is aligned with the antinodes of the device's

20   standing wave electromagnetic field.

The periodic gain region(s) **160** is composed of either small-molecular weight organic material or polymeric organic material, which fluoresce with a high quantum efficiency. The small-molecular weight organic material is typically deposited by high-vacuum (10^{-6} Torr) thermal evaporation, while the

25   conjugated polymers are usually formed by spin casting.

Unless otherwise specifically stated, use of the term "substituted" or "substituent" means any group or atom other than hydrogen. Additionally, when the term "group" is used, it means that when a substituent group contains a substitutable hydrogen, it is also intended to encompass not only the substituent's

30   unsubstituted form, but also its form further substituted with any substituent group or groups as herein mentioned, so long as the substituent does not destroy properties necessary for device utility. Suitably, a substituent group can be

halogen or can be bonded to the remainder of the molecule by an atom of carbon, silicon, oxygen, nitrogen, phosphorous, sulfur, selenium, or boron. The substituent can be, for example, halogen, such as chloro, bromo or fluoro; nitro; hydroxyl; cyano; carboxyl; or groups which can be further substituted, such as

5   alkyl, including straight or branched chain or cyclic alkyl, such as methyl, trifluoromethyl, ethyl, *t*-butyl, 3-(2,4-di-*t*-pentylphenoxy) propyl, and tetradecyl; alkenyl, such as ethylene, 2-butene; alkoxy, such as methoxy, ethoxy, propoxy, butoxy, 2-methoxyethoxy, *sec*-butoxy, hexyloxy, 2-ethylhexyloxy, tetradecyloxy, 2-(2,4-di-*t*-pentylphenoxy)ethoxy, and 2-dodecyloxyethoxy; aryl such as phenyl,

10   4-*t*-butylphenyl, 2,4,6-trimethylphenyl, naphthyl; aryloxy, such as phenoxy, 2-methylphenoxy, alpha- or beta-naphthyloxy, and 4-tolyloxy; carbonamido, such as acetamido, benzamido, butyramido, tetradecanamido, alpha-(2,4-di-*t*-pentyl-phenoxy)acetamido, alpha-(2,4-di-*t*-pentylphenoxy)butyramido, alpha-(3-pentadecylphenoxy)-hexanamido, alpha-(4-hydroxy-3-*t*-butylphenoxy)-

15   tetradecanamido, 2-oxo-pyrrolidin-1-yl, 2-oxo-5-tetradecylpyrrolin-1-yl, *N*-methyltetradecanamido, *N*-succinimido, *N*-phthalimido, 2,5-dioxo-1-oxazolidinyl, 3-dodecyl-2,5-dioxo-1-imidazolyl, and *N*-acetyl-*N*-dodecylamino, ethoxycarbonylamino, phenoxycarbonylamino, benzyloxycarbonylamino, hexadecyloxycarbonylamino, 2,4-di-*t*-butylphenoxycarbonylamino,

20   phenylcarbonylamino, 2,5-(di-*t*-pentylphenyl)carbonylamino, *p*-dodecyl-phenylcarbonylamino, *p*-tolylcarbonylamino, *N*-methylureido, *N,N*-dimethylureido, *N*-methyl-*N*-dodecylureido, *N*-hexadecylureido, *N,N*-dioctadecylureido, *N,N*-dioctyl-*N'*-ethylureido, *N*-phenylureido, *N,N*-diphenylureido, *N*-phenyl-*N*-*p*-tolylureido, *N*-(*m*-hexadecylphenyl)ureido, *N,N*-

25   (2,5-di-*t*-pentylphenyl)-*N'*-ethylureido, and *t*-butylcarbonamido; sulfonamido, such as methylsulfonamido, benzenesulfonamido, *p*-tolylsulfonamido, *p*-dodecylbenzenesulfonamido, *N*-methyltetradecylsulfonamido, *N,N*-dipropyl-sulfamoylamino, and hexadecylsulfonamido; sulfamoyl, such as *N*-methylsulfamoyl, *N*-ethylsulfamoyl, *N,N*-dipropylsulfamoyl, *N*-

30   hexadecylsulfamoyl, *N,N*-dimethylsulfamoyl, *N*-[3-(dodecyloxy)propyl]-sulfamoyl, *N*-[4-(2,4-di-*t*-pentylphenoxy)butyl]sulfamoyl, *N*-methyl-*N*-tetradecylsulfamoyl, and *N*-dodecylsulfamoyl; carbamoyl, such as *N*-

methylcarbamoyl, *N,N*-dibutylcarbamoyl, *N*-octadecylcarbamoyl, *N*-[4-(2,4-di-*t*-pentylphenoxy)butyl]carbamoyl, *N*-methyl-*N*-tetradecylcarbamoyl, and *N,N*-dioctylcarbamoyl; acyl, such as acetyl, (2,4-di-*t*-amylphenoxy)acetyl, phenoxycarbonyl, *p*-dodecyloxyphenoxycarbonyl methoxycarbonyl,

5   butoxycarbonyl, tetradecyloxycarbonyl, ethoxycarbonyl, benzyloxycarbonyl, 3-pentadecyloxycarbonyl, and dodecyloxycarbonyl; sulfonyl, such as methoxysulfonyl, octyloxysulfonyl, tetradecyloxysulfonyl, 2-ethylhexyloxy-sulfonyl, phenoxysulfonyl, 2,4-di-*t*-pentylphenoxysulfonyl, methylsulfonyl, octylsulfonyl, 2-ethylhexylsulfonyl, dodecylsulfonyl, hexadecylsulfonyl,

10   phenylsulfonyl, 4-nonylphenylsulfonyl, and *p*-tolylsulfonyl; sulfonyloxy, such as dodecylsulfonyloxy, and hexadecylsulfonyloxy; sulfinyl, such as methylsulfinyl, octylsulfinyl, 2-ethylhexylsulfinyl, dodecylsulfinyl, hexadecylsulfinyl, phenylsulfinyl, 4-nonylphenylsulfinyl, and *p*-tolylsulfinyl; thio, such as ethylthio, octylthio, benzylthio, tetradecylthio, 2-(2,4-di-*t*-pentylphenoxy)ethylthio,

15   phenylthio, 2-butoxy-5-t-octylphenylthio, and *p*-tolylthio; acyloxy, such as acetyloxy, benzoyloxy, octadecanoyloxy, *p*-dodecylamidobenzoyloxy, *N*-phenylcarbamoyloxy, *N*-ethylcarbamoyloxy, and cyclohexylcarbonyloxy; amine, such as phenylanilino, 2-chloroanilino, diethylamine, dodecylamine; imino, such as 1 (*N*-phenylimido)ethyl, *N*-succinimido or 3-benzylhydantoinyl; phosphate,

20   such as dimethylphosphate and ethylbutylphosphate; phosphite, such as diethyl and dihexylphosphite; a heterocyclic group, a heterocyclic oxy group or a heterocyclic thio group, each of which can be substituted and which contain a 3 to 7 membered heterocyclic ring composed of carbon atoms and at least one hetero atom selected from the group including oxygen, nitrogen, sulfur, phosphorous, or

25   boron. such as 2-furyl, 2-thienyl, 2-benzimidazolyloxy or 2-benzothiazolyl; quaternary ammonium, such as triethylammonium; quaternary phosphonium, such as triphenylphosphonium; and silyloxy, such as trimethylsilyloxy.

If desired, the substituents can themselves be further substituted
30   one or more times with the described substituent groups. The particular substituents used can be selected by those skilled in the art to attain the desired properties for a specific application and can include, for example, electron-

withdrawing groups, electron-donating groups, and steric groups. When a molecule can have two or more substituents, the substituents can be joined together to form a ring such as a fused ring unless otherwise provided. Generally, the above groups and substituents thereof can include those having up to 48

5   carbon atoms, typically 1 to 36 carbon atoms and usually less than 24 carbon atoms, but greater numbers are possible depending on the particular substituents selected. Substitution can include fused ring derivatives such as, but not limited to benzo-, dibenzo-, naphtha-, or dinaphtho-fused derivatives. These fused ring derivatives can be further substituted as well.

10   The periodic gain region(s) **160** (or emissive material) can be comprised of a single host material, but more commonly includes a host material doped with a guest compound (dopant) or compounds where light emission comes primarily from the dopant and can be of any color. These host-dopant combinations are advantageous since they result in very small unpumped

15   scattering/absorption losses for the gain media (can be less than 1 cm^{-1}). The dopant is usually chosen from highly fluorescent dyes, but phosphorescent compounds, e.g., transition metal complexes as described for OLED applications in WO 98/55561, WO 00/18851, WO 00/57676, and WO 00/70655 are also useful. Dopants are typically coated as 0.01 to 10% by weight into the host

20   material, wherein they can be selected to provide emitted light having hues of either red, green, or blue. An example of a useful host-dopant combination for red emitting layers is Alq as the host material and 1% L39 [4-(dicyanomethylene)-2-t-butyl-6-(1,1,7,7-tetramethyljulolidyl-9-enyl)-4H-pyran] as the dopant.

An important relationship for choosing a dye as a dopant is a

25   comparison of the absorption of the dopant material and emission of the host material. For efficient energy transfer (via Forster energy transfer) from the host to the dopant molecule, a necessary condition is that the absorption of the dopant overlaps the emission of the host material. Those skilled in the art are familiar with the concept of Forster energy transfer, which involves a radiationless transfer

30   of energy between the host and dopant molecules. An important relationship for choosing the host material is that the absorption of the host material significantly overlaps the emission spectrum of the pump-beam **180** light. In addition it is

preferred that the absorption of the host material or a host material plus a dopant is small at the laser emission wavelength of the device **100**. An acceptable level of absorption is that the absorption coefficient of the host plus dopant combination is less than 10 cm^{-1} at the wavelength of the laser emission.

5   Useful fluorescent emissive materials includes polycyclic aromatic compounds as described in I.B. Berlman, "Handbook of Fluorescence Spectra of Aromatic Molecules," Academic Press, New York, 1971 and EP 1 009 041. Tertiary aromatic amines with more than two amine groups can be used including oligomeric materials.

10   Another class of useful emissive materials (for host or dopants) include aromatic tertiary amines, where the latter is understood to be a compound containing at least one trivalent nitrogen atom that is bonded only to carbon atoms, at least one of which is a member of an aromatic ring. In one form the aromatic tertiary amine can be an arylamine, such as a monoarylamine,

15 diarylamine, triarylamine, or an oligomeric arylamine. Exemplary monomeric triarylamines are illustrated by Klupfel et al. U.S. Patent 3,180,730. Other suitable triarylamines substituted with one or more vinyl radicals and/or comprising at least one active hydrogen containing group are disclosed by Brantley et al. U.S. Patents 3,567,450 and 3,658,520.

20   A more preferred class of aromatic tertiary amines are those which include at least two aromatic tertiary amine moieties as described in U.S. Patents 4,720,432 and 5,061,569. Such compounds include those represented by structural Formula A.

$$\text{A} \qquad Q_1\diagdown_{G}\diagup Q_2$$

25 wherein:

         Q_1 and Q_2 are independently selected aromatic tertiary amine moieties; and

         G is a linking group such as an arylene, cycloalkylene, or alkylene group of a carbon to carbon bond.

In one embodiment, at least one of Q_1 or Q_2 contains a polycyclic fused ring

30 structure, e.g., a naphthalene. When G is an aryl group, it is conveniently a phenylene, biphenylene, or naphthalene moiety.

A useful class of triarylamines satisfying structural Formula A and containing two triarylamine moieties is represented by structural Formula B.

$$B \qquad R_1 - \underset{\underset{R_4}{|}}{\overset{\overset{R_2}{|}}{C}} - R_3$$
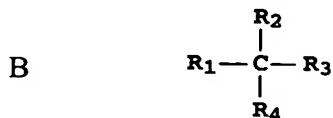
where:

5   R_1 and R_2 each independently represent a hydrogen atom, an aryl group, or an alkyl group or R_1 and R_2 together represent the atoms completing a cycloalkyl group; and

R_3 and R_4 each independently represent an aryl group, which is in turn substituted with a diaryl substituted amino group, as indicated by structural

10   Formula C.

$$C \qquad \underset{R_6}{\overset{R_5}{>}} N -$$

wherein R_5 and R_6 are independently selected aryl groups. In one embodiment, at least one of R_5 or R_6 contains a polycyclic fused ring structure, e.g., a naphthalene.

The host material can comprise a substituted or unsubstituted

15   triarylamine compound. Another class of aromatic tertiary amines are the tetraaryldiamines. Desirable tetraaryldiamines include two diarylamino groups, such as indicated by Formula C, linked through an arylene group. Useful tetraaryldiamines include those represented by Formula D.

$$D \qquad \underset{Ar}{\overset{R_7}{>}} N \left(Are \right)_n N \underset{R_9}{\overset{R_8}{<}}$$
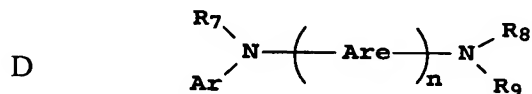
wherein:

20   each Are is an independently selected arylene group, such as a phenylene or anthracene moiety;

n is an integer of from 1 to 4; and

Ar, R_7, R_8, and R_9 are independently selected aryl groups.

In a typical embodiment, at least one of Ar, R_7, R_8, and R_9 is a polycyclic fused ring structure, e.g., a naphthalene.

The various alkyl, alkylene, aryl, and arylene moieties of the foregoing structural Formulae A, B, C, D, can each in turn be substituted. Typical substituents include

5   alkyl groups, alkoxy groups, aryl groups, aryloxy groups, and halogens such as fluoride, chloride, and bromide. The various alkyl and alkylene moieties typically contain from 1 to about 6 carbon atoms. The cycloalkyl moieties can contain from 3 to about 10 carbon atoms, but typically contain five, six, or seven carbon atoms--e.g., cyclopentyl, cyclohexyl, and cycloheptyl ring structures. The aryl and

10   arylene moieties are usually phenyl and phenylene moieties.

The emissive material can be formed of a single or a mixture of aromatic tertiary amine compounds. Specifically, one can employ a triarylamine, such as a triarylamine satisfying the Formula B, in combination with a tetraaryldiamine, such as indicated by Formula D. The host material can include a

15   substituted or unsubstituted dicarbazole-biphenyl compound. Illustrative of useful aromatic tertiary amines is the following:

4,4'-*N,N*'-dicarbazole-1,1'-biphenyl (CBP) (D1)

4,4'-Bis[N-(1-naphthyl)-N-phenylamino]biphenyl (D2)

4,4'-Bis[N-(1-naphthyl)-N-(2-naphthyl)amino]biphenyl (D3)

20   4,4'-Bis[N-(2-naphthyl)-N-*p*-tolylamino]biphenyl (D4)

1,1-Bis(4-di-*p*-tolylaminophenyl)cyclohexane

1,1-Bis(4-di-*p*-tolylaminophenyl)-4-phenylcyclohexane

4,4'-Bis(diphenylamino)quadriphenyl

Bis(4-dimethylamino-2-methylphenyl)-phenylmethane

25   N,N,N-Tri(*p*-tolyl)amine

4-(di-p-tolylamino)-4'-[4(di-*p*-tolylamino)-styryl]stilbene

N,N,N',N'-Tetra-*p*-tolyl-4-4'-diaminobiphenyl

N,N,N',N'-Tetraphenyl-4,4'-diaminobiphenyl

N,N,N',N'-tetra-1-naphthyl-4,4'-diaminobiphenyl

30   N,N,N',N'-tetra-2-naphthyl-4,4'-diaminobiphenyl

N-Phenylcarbazole

4,4"-Bis[N-(1-naphthyl)-N-phenylamino]p-terphenyl

4,4'-Bis[N-(2-naphthyl)-N-phenylamino]biphenyl

4,4'-Bis[N-(3-acenaphthenyl)-N-phenylamino]biphenyl

1,5-Bis[N-(1-naphthyl)-N-phenylamino]naphthalene

4,4'-Bis[N-(9-anthryl)-N-phenylamino]biphenyl

5   4,4"-Bis[N-(1-anthryl)-N-phenylamino]-*p*-terphenyl

4,4'-Bis[N-(2-phenanthryl)-N-phenylamino]biphenyl

4,4'-Bis[N-(8-fluoranthenyl)-N-phenylamino]biphenyl

4,4'-Bis[N-(2-pyrenyl)-N-phenylamino]biphenyl

4,4'-Bis[N-(2-naphthacenyl)-N-phenylamino]biphenyl

10   4,4'-Bis[N-(2-perylenyl)-N-phenylamino]biphenyl

4,4'-Bis[N-(1-coronenyl)-N-phenylamino]biphenyl

2,6-Bis(di-*p*-tolylamino)naphthalene

2,6-Bis[di-(1-naphthyl)amino]naphthalene

2,6-Bis[N-(1-naphthyl)-N-(2-naphthyl)amino]naphthalene

15   N,N,N',N'-Tetra(2-naphthyl)-4,4"-diamino-*p*-terphenyl

4,4'-Bis{N-phenyl-N-[4-(1-naphthyl)-phenyl]amino}biphenyl

4,4'-Bis[N-phenyl-N-(2-pyrenyl)amino]biphenyl

2,6-Bis[N,N-di(2-naphthyl)amine]fluorene

1,5-Bis[N-(1-naphthyl)-N-phenylamino]naphthalene

20   4,4',4"-tris[(3-methylphenyl)phenylamino]triphenylamine.

The host material can comprise a substituted or unsubstituted aza-aromatic

compound. For example, the host material can comprise a substituted or

unsubstituted acridine, quinoline, purine, phenazine, phenoxazine, or

phenanthroline compound. Carbazole derivatives are useful hosts. Useful

25   examples of phenanthroline materials include 2,9-dimethyl-4,7-diphenyl-1,10-

phenanthroline and 4,7-diphenyl-1,10-phenanthroline.

Host and dopant molecules include, but are not limited to, those

disclosed in U.S. Patents 4,768,292; 5,141,671; 5,150,006; 5,151,629; 5,405,709;

5,484,922; 5,593,788; 5,645,948; 5,683,823; 5,755,999; 5,928,802; 5,935,720;

30   5,935,721; and 6,020,078.

Metal complexes of 8-hydroxyquinoline and similar derivatives

(Formula E) constitute one class of useful host materials capable of supporting

electroluminescence, and are particularly suitable for light emission of wavelengths longer than 500 nm, e.g., green, yellow, orange, and red.

E
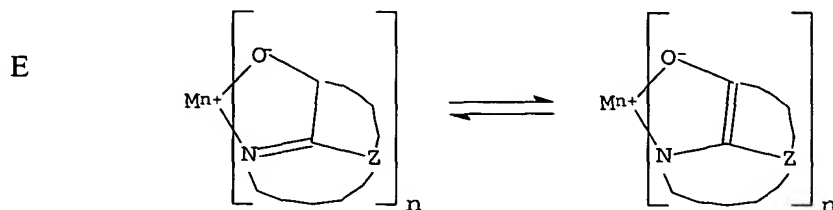
wherein:

M represents a metal;

n is an integer of from 1 to 3; and

Z independently in each occurrence represents the atoms completing a nucleus having at least two fused aromatic rings.

From the foregoing it is apparent that the metal can be monovalent, divalent, trivalent, or tetravalent metal. The metal can, for example, be an alkali metal, such as lithium, sodium, or potassium; an alkaline earth metal, such as magnesium or calcium; an earth metal, such aluminum or gallium, or a transition metal such as zinc or zirconium. Generally any monovalent, divalent, trivalent, or tetravalent metal known to be a useful chelating metal can be employed.

Z completes a heterocyclic nucleus containing at least two fused aromatic rings, at least one of which is an azole or azine ring. Additional rings, including both aliphatic and aromatic rings, can be fused with the two required rings, if required. To avoid adding molecular bulk without improving on function the number of ring atoms is usually maintained at 18 or less.

The host material can comprise a substituted or unsubstituted chelated oxinoid compound.

Illustrative of useful chelated oxinoid compounds are the following:

CO-1: Aluminum trisoxine [alias, tris(8-quinolinolato)aluminum(III)]

CO-2: Magnesium bisoxine [alias, bis(8-quinolinolato)magnesium(II)]

CO-3: Bis[benzo{f}-8-quinolinolato]zinc (II)

CO-4: Bis(2-methyl-8-quinolinolato)aluminum(III)-μ-oxo-bis(2-methyl-8-quinolinolato) aluminum(III)

CO-5: Indium trisoxine [alias, tris(8-quinolinolato)indium]

CO-6: Aluminum tris(5-methyloxine) [alias, tris(5-methyl-8-quinolinolato) aluminum(III)]

CO-7: Lithium oxine [alias, (8-quinolinolato)lithium(I)]

5   CO-8: Gallium oxine [alias, tris(8-quinolinolato)gallium(III)]

CO-9: Zirconium oxine [alias, tetra(8-quinolinolato)zirconium(IV)]

The host material can include a substituted or unsubstituted anthracene compound.

Derivatives of 9,10-di-(2-naphthyl)anthracene (Formula F)
10   constitute one class of useful hosts capable of supporting photoluminescence, and are particularly suitable for light emission of wavelengths longer than 400 nm, e.g., blue, green, yellow, orange or red.
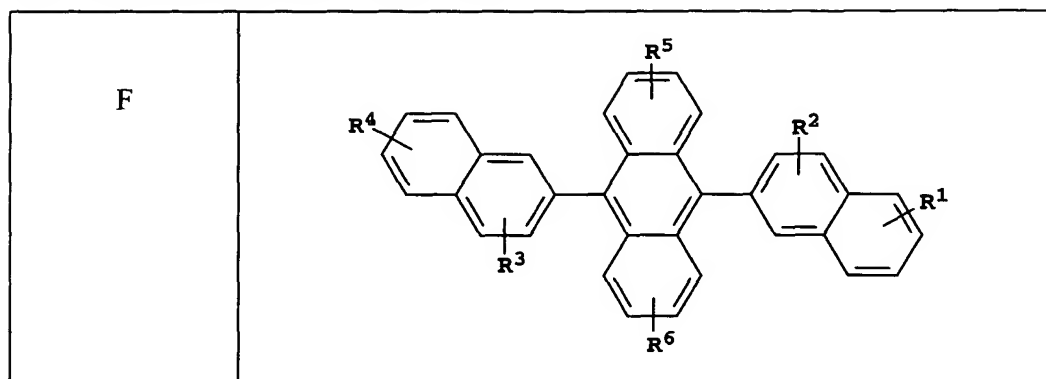
wherein R^1, R^2, R^3, R^4, R^5, and R^6 represent one or more substituents on each ring
15   where each substituent is individually selected from the following groups:

Group 1: hydrogen, or alkyl of from 1 to 24 carbon atoms;

Group 2: aryl or substituted aryl of from 5 to 20 carbon atoms;

Group 3: carbon atoms from 4 to 24 necessary to complete a fused aromatic ring of anthracenyl, pyrenyl, or perylenyl;
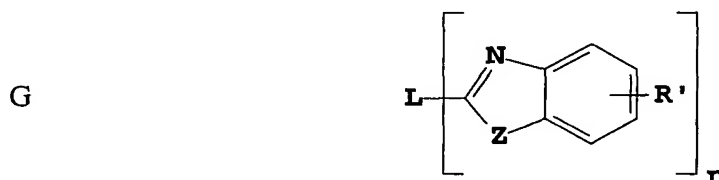
20   Group 4: heteroaryl or substituted heteroaryl of from 5 to 24 carbon atoms as necessary to complete a fused heteroaromatic ring of furyl, thienyl, pyridyl, quinolinyl or other heterocyclic systems;

Group 5: alkoxylamino, alkylamino, or arylamino of from 1 to 24 carbon atoms; and

25   Group 6: fluorine, chlorine, bromine or cyano.

Illustrative examples include 9,10-di-(2-naphthyl)anthracene (F1) and 2-*t*-butyl-9,10-di-(2-naphthyl)anthracene (F2). Other anthracene derivatives can be useful as a host, including derivatives of 9,10-bis-(4-(2,2'-diphenylethenyl)phenyl)anthracene.

5   Benzazole derivatives (Formula G) constitute another class of useful hosts capable of supporting photoluminescence, and are particularly suitable for light emission of wavelengths longer than 400 nm, e.g., blue, green, yellow, orange or red.

G

where:

10   n is an integer of 3 to 8;

Z is O, NR or S; and

R and R' are individually hydrogen; alkyl of from 1 to 24 carbon atoms, for example, propyl, t-butyl, heptyl, and the like; aryl or hetero-atom substituted aryl of from 5 to 20 carbon atoms for example phenyl and naphthyl,

15   furyl, thienyl, pyridyl, quinolinyl and other heterocyclic systems; or halo such as chloro, fluoro; or atoms necessary to complete a fused aromatic ring; and

L is a linkage unit including alkyl, aryl, substituted alkyl, or substituted aryl, which conjugately or unconjugately connects the multiple benzazoles together. An example of a useful benzazole is 2, 2', 2"-(1,3,5-

20   phenylene)tris[1-phenyl-1H-benzimidazole].

The host material can comprise a substituted or unsubstituted benzoxazole compound, a substituted or unsubstituted benzthiazole compound, or a substituted or unsubstituted benzimidazole compound. The host material can comprise a substituted or unsubstituted oxazole compound, a substituted or

25   unsubstituted triazole compound, or a substituted or unsubstituted oxadiazole compound. Useful examples of oxazole compounds include 1,4-bis(5-phenyloxazol-2-yl)benzene, 1,4-bis(4-methyl-5-phenyloxazol-2-yl)benzene, and 1,4-bis(5-(*p*-biphenyl)oxazol-2-yl)benzene. Useful examples of oxadiazole

compounds include 2-(4-biphenylyl)-5-phenyl-1,3,4-oxadiazole and 2-(4-biphenylyl)-5-(4-tert-butylphenyl)-1,3,4-oxadiazole. Useful examples of triazole compounds include 3-(4-biphenylyl)-4-phenyl-5-tert-butylphenyl-1,2,4-triazole.

Distyrylarylene derivatives are also useful as host materials or

5   dopant materials, many examples are described in U.S. Patent 5,121,029. Useful emissive materials (hosts and dopants) can have the general Formulae (H) or (I):

$$X-CH=CH-Y-CH=CH-Z \qquad (H)$$
$$X-(CH=CH)_n-Z \qquad (I)$$
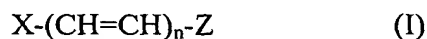
where:

X and Z are independently a substituted or unsubstituted aromatic group or a substituted or unsubstituted aromatic complex ring group having one nitrogen atom;

n equals 1, 2, or 3; and

Y is a divalent aromatic group or a divalent aromatic complex ring group having one nitrogen atom. Useful examples include 1,4-bis(2-methylstyryl)-benzene, 4,4'-(9,10-anthracenediyldi-2,1-ethenediyl)bis(N,N-bis(4-methylphenyl)-benzenamine, 4,4'-(1,4-naphthalenediyldi-2,1-ethenediyl)bis(N,N-bis(4-methylphenyl)benzenamine, and 4,4'-(1,4-phenylenedi-2,1-ethenediyl)bis(N,N-(4-tolyl))benzeneamine.

The dopant is selected to provide emission between 300-1700 nm.

10   The dopant can be selected from fluorescent or phosphorescent dyes. Useful fluorescent dopants include materials as described as host materials above. Other useful fluorescent dopants include, but are not limited to, derivatives of substituted or unsubstituted anthracene, tetracene, xanthene, perylene, rubrene, coumarin, rhodamine, and quinacridone, dicyanomethylenepyran compounds,

15   thiopyran compounds, polymethine compounds, pyrilium and thiapyrilium compounds, fluorene derivatives, periflanthene derivatives, indenoperylene derivatives, bis(azinyl)amine boron compounds, bis(azinyl)methane compounds, napthyridine, fluoranthene, furan, indole, thiaphene, benzoxanthene, pyrene, peropyrene, terphenyl, quaterphenyl, quinquephenyl, sexiphenyl, anthanthrene,

20   bisanthrene compounds, N,N,N',N'-tetrasubstituted benzidene derivatives, N,N,N',N'-tetrarylbenzidene derivatives and carbostyryl compounds or

combinations thereof. Derivatives of these classes of materials can also serve as useful host materials or combinations thereof. Host materials will often be compounds containing at least three phenylene moieties.

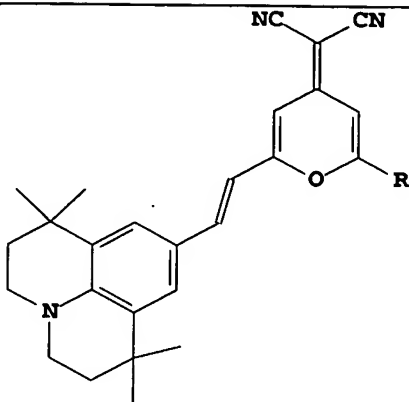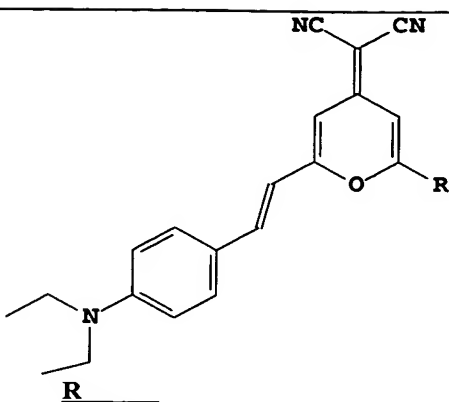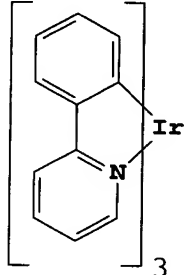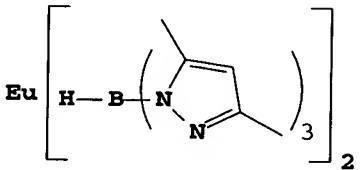Illustrative examples of useful dopants include, but are not limited to, the following:

L1

L2

L3

L4

L5

L6
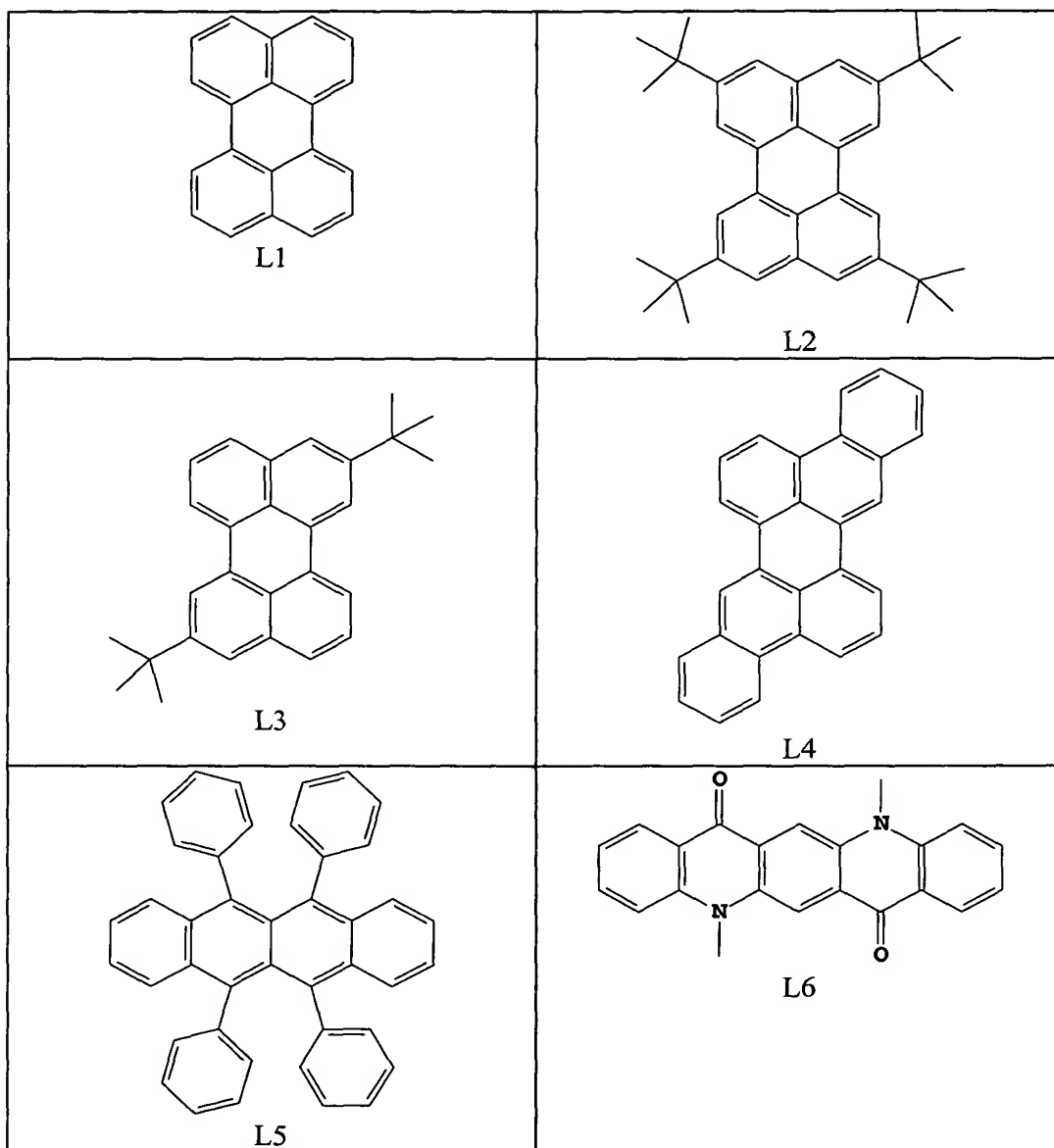
L7

L8

	X	R1	R2
L9	O	H	H
L10	O	H	Methyl
L11	O	Methyl	H
L12	O	Methyl	Methyl
L13	O	H	t-butyl
L14	O	t-butyl	H
L15	O	t-butyl	t-butyl
L16	S	H	H
L17	S	H	Methyl
L18	S	Methyl	H
L19	S	Methyl	Methyl
L20	S	H	t-butyl
L21	S	t-butyl	H
L22	S	t-butyl	t-butyl

	X	R1	R2
L23	O	H	H
L24	O	H	Methyl
L25	O	Methyl	H
L26	O	Methyl	Methyl
L27	O	H	t-butyl
L28	O	t-butyl	H
L29	O	t-butyl	t-butyl
L30	S	H	H
L31	S	H	Methyl
L32	S	Methyl	H
L33	S	Methyl	Methyl
L34	S	H	t-butyl
L35	S	t-butyl	H
L36	S	t-butyl	t-butyl

	R
L37	phenyl
L38	methyl
L39	t-butyl
L40	mesityl

	R
L41	phenyl
L42	methyl
L43	t-butyl
L44	mesityl

L45

L46

L47

L48

L49

L50

L51

L52

L53	L54
L55	L56
L57	L58
L59	L60
L61	L62
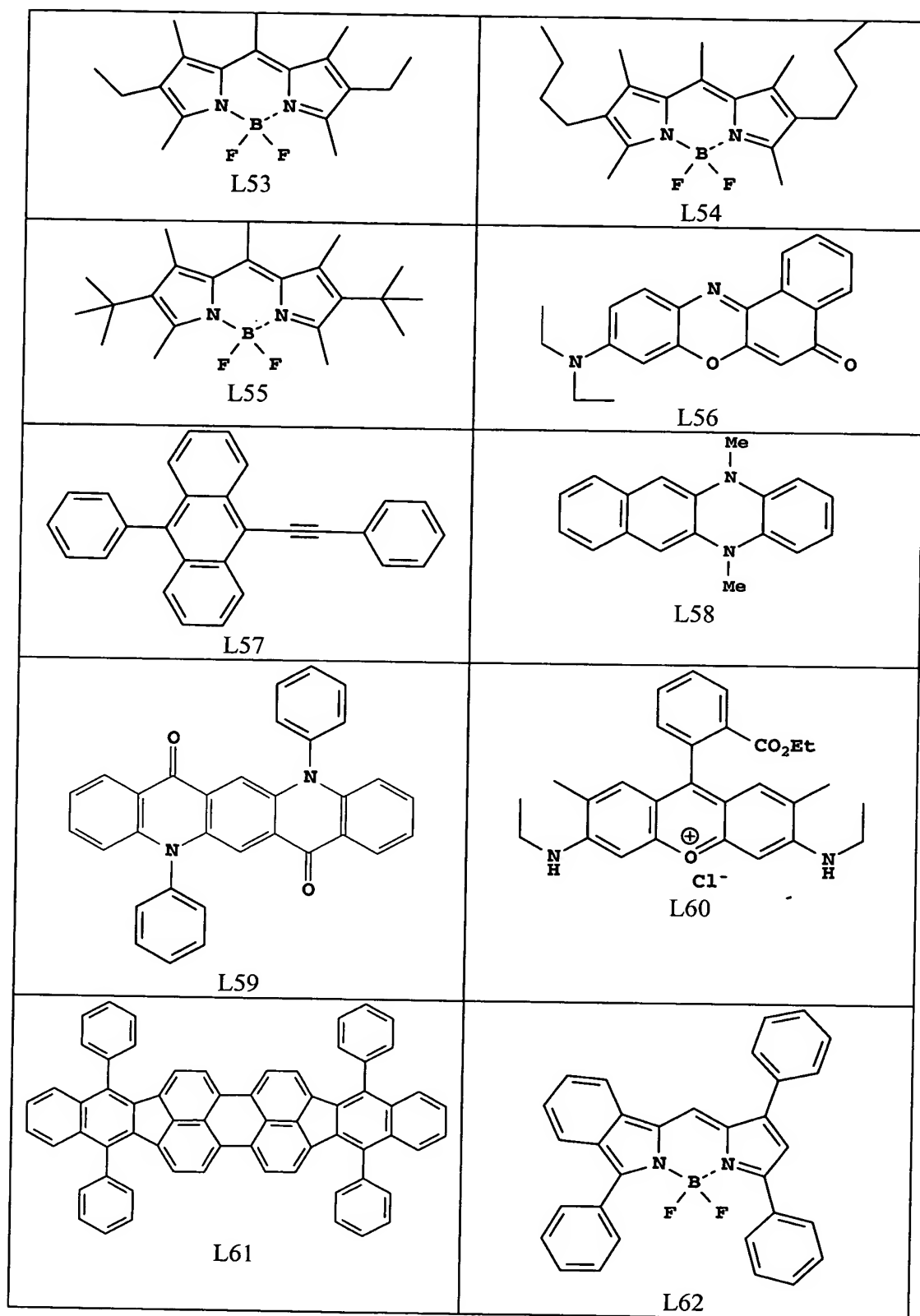
Other emissive materials include various heterocyclic optical brighteners as described in U.S. Patent 4,539,507.

The emissive material can also be a polymeric material, a blend of

5 two or more polymeric materials, or a doped polymer or polymer blend. The emissive material can also be a combination of more than one nonpolymeric and polymeric materials with or without dopants. Typical dopants are listed previously for nonpolymeric molecules. Nonpolymeric dopants can be molecularly dispersed into the polymeric host, or the dopant could be added by

10 copolymerizing a minor constituent into the host polymer. Typical polymeric materials include, but are not limited to, substituted and unsubstituted poly(p-phenylenevinylene) (PPV) derivatives, substituted and unsubstituted poly(p-phenylene) (PPP) derivatives, substituted and unsubstituted polyfluorene (PF) derivatives, substituted and unsubstituted poly(p-pyridine), substituted and

15 unsubstituted poly(p-pyridalvinylene) derivatives, and substituted, unsubstituted poly(p-phenylene) ladder and step-ladder polymers, and copolymers thereof as taught by Diaz-Garcia et al. in U.S. Patent 5,881,083 and references therein. The substituents include but are not limited to alkyls, cycloalkyls, alkenyls, aryls, heteroaryls, alkoxy, aryloxys, amino, nitro, thio, halo, hydroxy, and cyano.

20 Typical polymers are poly(p-phenylene vinylene), dialkyl-, diaryl-, diamino-, or dialkoxy-substituted PPV, mono alkyl-mono alkoxy-substituted PPV, mono aryl-substituted PPV, 9,9'-dialkyl or diaryl-substituted PF, 9,9'-mono alky-mono aryl substituted PF, 9-mono alky or aryl substituted PF, PPP, dialkyl-, diamino-, diaryl-, or dialkoxy-substituted PPP, mono alkyl-, aryl-, alkoxy-, or amino-

25 substituted PPP. In addition, polymeric materials can be used such as poly(N-vinylcarbazole) (PVK), polythiophenes, polypyrrole, polyaniline, and copolymers such as poly(3,4-ethylenedioxythiophene)/poly(4-styrenesulfonate) also called PEDOT/PSS.

The organic materials mentioned above are suitably deposited

30 through sublimation, but can be deposited from a solvent with an optional binder to improve film formation. If the material is a polymer, solvent deposition is usually preferred. The material to be deposited by sublimation can be vaporized

from a sublimator "boat" often comprised of a tantalum material, e.g., as described in U.S. Patent 6,237,529, or can be first coated onto a donor sheet and then sublimed in closer proximity to the substrate. Layers with a mixture of materials can utilize separate sublimator boats or the materials can be pre-mixed

5   and coated from a single boat or donor sheet. Patterned deposition can be achieved using shadow masks, integral shadow masks (U.S. Patent 5,294,870), spatially-defined thermal dye transfer from a donor sheet (U.S. Patents 5,688,551; 5,851,709; and 6,066,357) and inkjet method (U.S. Patent 6,066,357).

Most organic laser devices are sensitive to moisture or oxygen, or

10   both, so they are commonly sealed in an inert atmosphere such as nitrogen or argon. Desiccant such as alumina, bauxite, calcium sulfate, clays, silica gel, zeolites, alkaline metal oxides, alkaline earth metal oxides, sulfates, or metal halides and perchlorates can be incorporated into the sealed device. Methods for encapsulation and desiccation include, but are not limited to, those described in

15   U.S. Patent No. 6,226,890. In addition, barrier layers such as SiOx, Teflon, and alternating inorganic/polymeric layers are known in the art for encapsulation.

For the spacer layer **170** it is preferred to use a material which is highly transparent to both the laser emission **190** and the pump-beam **180**. In this embodiment 1,1-Bis-(4-bis(4-methyl-phenyl)-amino-phenyl)-cyclohexane

20   (TAPC) was chosen as the spacer material, since it has very low absorption throughout the visible and near UV spectrum and its index of refraction is slightly lower than that of most organic host materials. This refractive index difference is useful since it helps in maximizing the overlap between the standing e-field antinodes and the periodic gain region(s) **160**. Besides organic spacer materials,

25   the spacer layer **170** can also be composed of inorganic materials, such as, SiO_2, since it has low absorption and its index of refraction is less than that of organic host materials. When using inorganic-based spacer layers, the materials can be deposited either by thermal evaporation or by e-beam at low deposition temperatures (around 70°C).

30   Following the active region **130** is deposited the top dielectric stack **140**. The top dielectric stack **140** is spaced from the bottom dielectric stack **120** and reflective to light over a predetermined range of wavelengths. Its composition

is analogous to that of the bottom dielectric stack **120**. Since the top dielectric stack **140** is deposited over an active region **130**, which contains organics, its deposition temperature must be kept low in order to avoid melting the organics. As a result, a typical deposition temperature for the top dielectric stack **140** is

5 70°C. In order to obtain good lasing performance, it is preferred that the peak reflectivities of the top and bottom dielectric stacks be greater than 99%, where smaller values result in larger lasing linewidths.

The two-dimensional laser array device **100** is optically driven by an incident pump-beam source **180** and emits laser emission **190**. Depending on

10 the lasing power density threshold of the organic laser cavity, the pump-beam can be either focused laser light or incoherent LED light. FIG. 1 shows laser emission **190** through the substrate **110**. Alternatively, the laser structure could be optically pumped through the substrate **110** with the laser emission **190** through the top dielectric stack **140** by proper design of the dielectric stack reflectance properties.

15 In the case of an opaque (e.g., silicon) substrate, both optical pumping and laser emission occurs through the top dielectric stack **140**. The operation of the optically pumped organic laser array device occurs by the following means. The pump-beam **180** transmits through the top dielectric stack **140** and is absorbed by the periodic gain region(s) **160**, wherein some fraction of the pump-beam energy

20 is re-emitted as longer wavelength laser light. When the pump-beam **180** enters through the top dielectric stack **140**, to ensure that the laser output **190** mainly exits through the substrate **110**, it is necessary to choose the top dielectric stack peak reflectance to be greater than the bottom dielectric stack peak reflectance. To improve the power conversion efficiency of the device, it is common practice

25 to add additional dielectric layers to both dielectric stacks, such that, the bottom dielectric stack **120** is highly reflective to the pump-beam **180** and the top dielectric stack **140** is highly transmissive to the pump-beam **180**. The laser light is emitted by the laser pixels **200**.

In an alternative embodiment of the present invention, the top

30 dielectric stack **140** is replaced by the deposition of a reflective metal mirror layer. Typical metals are silver or aluminum, which have reflectivities in excess of 90%. It is preferred that the metals be deposited by vacuum thermal evaporation to

avoid causing damage to the underlying organic layers. In this alternative embodiment, both the pump-beam **180** and the laser emission **190** would proceed through the substrate **110**. Besides this change, the layer structure and operation of the laser array device is analogous to the case where the both mirrors are

5   composed of multilayer dielectrics.

FIG. 3 shows another embodiment of the present invention, a two-dimensional laser array device **102**. This device is a variation of the one illustrated in FIG. 1. In FIG. 1 the active region **130** is deposited directly over the etched surface of the bottom dielectric stack **120**; however, this would result in the

10   active region **130** and top dielectric stack **140** being deposited on a non-planar (corrugated) surface. For certain multilayer stack combinations, such as, TiO_2-SiO_2, deposition on a corrugated surface can lead to columnar growth of the stacks. As a result, there is enhanced scattering losses in the top dielectric stack **140** and possibly also in the active region **130**. To overcome this problem, the

15   etched surface of the bottom dielectric stack **120** is planarized by a planarization layer **155** prior to depositing the active region **130**. One embodiment of the planarization layer **155** is polyimide for the Ta_2O_5-SiO_2 or TiO_2-SiO_2 multilayer stack systems. Following the creation of the etched regions **150**, 2 to 3 microns of polyimide are deposited on the surface of the bottom dielectric stack **120** by spin

20   casting and then hardened by a bake at temperatures ranging from 180 to 250°C. Next using chemical mechanical polishing (CMP) techniques which are well-known in the art, the polyimide is polished until it is flush (or within a couple tens of nanometers) with the top surface of the bottom dielectric stack **120** at the positions of the laser pixels **200**. Because of the large difference in the polish

25   rates of polyimide and oxides in standard CMP slurries, it is straightforward to have the polishing stop just as it begins to polish the oxide layers at the positions of the laser pixels **200**. A second embodiment of the planarization layer **155** is SiO_2 for the Ta_2O_5-SiO_2 multilayer dielectric stack system. In this case, the top layer of the bottom dielectric stack **120** is a thin layer of Si_3N_4. The silicon nitride

30   can be deposited by chemical vapor deposition (CVD) at a temperature range of 300-400°C and in a thickness range of 10 to 200 nm. Following the formation of the etched region **150** (where the etch goes through the nitride layer and 1 to 2

periods of the bottom dielectric stack **120**), the planarization layer **155** of SiO_2 is deposited at a thickness of 0.75 to 2.0 μm by either CVD or thermal evaporation. As for the polyimide embodiment, CMP is used with another common slurry to polish the SiO_2 until it is flush (or within a couple tens of nanometers) with the top

5 of the silicon nitride layer. As result of a polish selectivity of greater than 3.5:1, it is again straightforward to stop the polishing as it begins to polish the top of the silicon nitride layer. A third embodiment of the planarization layer **155** is polymethyl-methacrylate (PMMA) for any multilayer dielectric stack system. In this case PMMA is spun cast over the etched surface of the bottom dielectric stack

10 **120** to a thickness range of .5 to 3.0 μm, followed by a conventional bake at 150 to 220°C. Scanning electron microscope (SEM) images reveal that a 3:1 or 4:1 PMMA thickness to etch depth ratio typically results in the planarization of the PMMA surface. Besides these three embodiments for planarization, other methodologies are possible as practiced by those skilled in the art. In summary,

15 the addition of the planarization layer **155** following the creation of the etched regions **150** and prior to the deposition of the active region **130**, leads to less scattering loss in the active region **130** and top dielectric stack **140** and results in higher power conversion efficiencies.

FIG. 4 shows another embodiment of the present invention, a two-
20 dimensional laser array device **104**. In order to minimize scattering losses and correspondingly boost the power conversion efficiency, it is preferred that the etched surface of the bottom dielectric stack be removed from the active region **130** where the intensity of the standing e-field is highest. As a result, the bottom dielectric stack is deposited in two parts, a first portion of the bottom dielectric

25 stack **122** and a second portion of the bottom dielectric stack **124**, whereby the reflectance modulation is obtained by forming an etched region **150** in the surface of the first portion of the bottom dielectric stack **122**. In order to distance the etched region **150** from the active region **130**, it is preferred that the first portion of the bottom dielectric stack **122** contain at most 3 to 5 dielectric layers which

30 reflect the laser light. For cases where additional dielectric layers are added to the bottom stack for reflecting the pump-beam **180** back into the active region **130**, these layers are to be deposited first in the first portion of the bottom dielectric

stack **122**. The second portion of the bottom dielectric stack **124** is deposited over the first portion of the bottom dielectric stack **122** after having formed the etched region **150**. As shown schematically in FIG. 4, the second portion of the bottom dielectric stack **124** fills the etched region **150**. The second portion of the bottom

5   dielectric stack **124** is composed of alternating layers of high and low refractive index dielectric materials, such as, TiO_2 and SiO_2, respectively. As for the first portion, the second portion is typically deposited by e-beam at a temperature of 240°C.

FIG. 5 shows another embodiment of the present invention, a two-

10   dimensional laser array device **106**. This device is a variation of the one illustrated in FIG. 4. In FIG. 4 the second portion of the bottom dielectric stack **124** is grown directly on the etched region **150**. As a result, the stack is deposited on a non-planar (corrugated) surface. For certain multilayer stack combinations, such as, TiO_2-SiO_2, deposition on a corrugated surface can lead to columnar

15   growth of the stacks. As a result, there is enhanced scattering losses in the second portion of the bottom dielectric stack **124**. To overcome this problem, the etched surface of the first portion of the bottom dielectric stack **122** is planarized by the planarization layer **155** prior to depositing the second portion of the bottom dielectric stack **124**. As discussed relative to FIG. 3, there are at least three

20   embodiments of the planarization layer, namely, using polyimide on oxide surfaces, SiO_2 on nitride surfaces, and PMMA on all surfaces. Besides these three embodiments for planarization, other methodologies are possible as practiced by those skilled in the art. In summary, the addition of the planarization layer **155** following the creation of the etched regions **150** and prior to the deposition of the

25   second portion of the bottom dielectric stack **124**, leads to less scattering loss in the second portion of the bottom dielectric stack **124**, active region **130** and top dielectric stack **140** and results in higher power conversion efficiencies.

The following example is presented as further understandings of the present invention and is not to be construed as limitations thereon.

30   **Example 1**

In order to determine the lasing characteristics of the two-dimensional laser array of FIGS. 1 and 2, laser structures were grown on pre-

cleaned 6-inch quartz substrates. Over the substrate was deposited, by conventional electron-beam deposition, the bottom dielectric stack **120**, which was composed of alternating high and low refractive index layers of TiO_2 and SiO_2, respectively. The quarter-wave layers of TiO_2 and SiO_2 were designed to

5   have a lasing wavelength of 560 nm, such that, the measured peak reflectance at 560 nm was ~99.4%. In order to increase the absorption of the pump-beam **180**, additional TiO_2 and SiO_2 layers were added (they are the first layers to be deposited on the substrate **110**) to the bottom dielectric stack **120** in order to boost the reflectance at 405 nm to 90%. Next, standard photolithographic and etching

10   techniques were used to pattern the bottom dielectric stack **120** so as to create a two-dimensional random array of 3.5-5.5 μm diameter circular pillars, with a minimum edge-to-edge separation of 0.6 μm. With regard to creating the random circular pillar arrangement on the top surface of the bottom dielectric stack **120**, the photolithography mask of randomly sized and positioned circles was formed

15   by using a conventional random packing algorithm. A conventional fluorine-based dry etchant was used to etch to a depth of 297 nm in the interpixel regions **210**. Following the etch was deposited, by high vacuum thermal evaporation, the active region **130**, where in order was grown 153 nm of TAPC, 25 nm of Alq with 0.5% of [10-(2-benzothiazolyl)-2,3,6,7-tetrahydro-1,1,7,7-tetramethyl-

20   1H,5H,11H-[1]Benzopyrano[6,7,8-ij]quinolizin-11-one] (C545T), 140 nm of TAPC, 25 nm of Alq with 0.5% of C545T and 153 nm of TAPC. Lastly, the top dielectric stack **140** was deposited by low temperature electron-beam deposition, such that, the measured temperature of the quartz substrate was kept below 72° C. It was composed of alternating high and low refractive index layers of TiO_2 and

25   SiO_2, respectively. The resulting top stack dielectric mirror had a measured peak reflectance of ~99.98% at 560 nm.

        To test the device for its spectral and angular characteristics, the laser array was optically pumped as illustrated in FIG. 1 (at normal incidence to the top dielectric stack **140**) using the 405 nm output from a 5 mW Nichia laser

30   diode. The pump laser produced 50 nsec laser pulses at a repetition rate of 50 KHz. The pump-beam intensity was adjusted by the combination of two neutral density wheels and it was focused onto the laser cavity surface using a 1000 mm

focal-length lens. The resulting measured pump-beam **180** spot size on the device

surface was 177 x 243 μm. The laser output **190** from the cavity was focused on

to the entrance slit of a JY-Horiba double monochrometer (0.55 m) by the

combination of a 35 mm f1.4 lens and a 100 mm f4 lens nearest the slit (resulting

5   in a 2.9X magnification of the laser's near-field image). The resolution of the

monochrometer is approximately 0.08 nm; its output was detected by a cooled

Hamamatsu photomultiplier tube. To get the angular dependence of the laser

output **190**, the device was tilted at angles of 0, 4, and 15° with respect to the optic

axis defined by the pump-beam **180**.

10   FIG. 6 shows the angular dependence of the laser spectrum

collected by the 0.36 numerical aperture lens, where the two neutral density

wheels were adjusted to give a pump-beam **180** power density at the device

surface of 0.042 W/cm^2. With regard to the 0° spectrum, the laser output has two

main peaks at 558.7 and 558 nm, which correspond to the first and second-order

15   transverse modes from lasing within a single pixel. After those two main peaks,

the lasing intensity begins to rapidly tail off, where by 543 nm it is effectively in

the noise. For the 4°spectrum, the intensity of the two main laser peaks is about

half that of the 0° case. Finally for the 15° spectrum, the two main laser peaks are

gone, with signal only coming from the higher-order array modes (lasing mode

20   traveling across the structure and reflecting off of many neighboring pixels). The

integrated lasing intensities of the three cases (0, 4, and 15°) are 1.0, 0.45, and

0.14, respectively, in normalized units. Thus, the angular half-width of the laser

output is somewhat less than 4°. With regard to the spectral width of the laser

emission, FIG. 6 shows that it is less than 5 nm. Consequently, forming randomly

25   sized and spaced laser pixels results in spectrally and angularly narrowed laser

emission for two-dimensional organic VCSEL laser array devices.

           The invention has been described in detail with particular reference

to certain preferred embodiments thereof, but it will be understood that variations

and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

100	laser array device
102	laser array device
104	laser array device
106	laser array device
110	substrate
120	bottom dielectric stack
122	first portion of the bottom dielectric stack
124	second portion of the bottom dielectric stack
130	active region
140	top dielectric stack
150	etched region
155	planarization layer
160	periodic gain region
170	spacer layer
180	pump-beam
190	laser emission
200	laser pixel
210	interpixel region